EXPERIMENTAL VERIFICATION OF THE LOAD-FOLLOWING POTENTIAL OF A HOT DRY ROCK GEOTHERMAL RESERVOIR

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ABSTRACT

A recent 6-day flow experiment conducted at the Los Alamos National Laboratory's Fenton Hill Hot Dry Rock (HDR) test site in north-central New Mexico has verified that an HDR reservoir has the capability for a significant, and very rapid, increase in power output upon demand. The objective of this cyclic load-following experiment was to investigate the performance of the reservoir in a nominal high-backpressure (2200 psi) baseload operating condition upon which was superimposed greatly increased power production for a 4-hour period each day. In practice, this enhanced production was accomplished by dropping the production well backpressure from the preexisting level of 2200 psi down to about 500 psi to rapidly drain the fluid stored in the pressure-dilated joints surrounding the production well. During the last cycle of this six-cycle test, the mean production conditions were 146.6 gpm for 4 hours at a temperature of 189°C, followed by 92.4 gpm for 20 hours at a temperature of 183°C. These flow and temperature values indicate a flow enhancement of 59%, and a power enhancement of 65% during the high-production period. The time required to increase the reservoir power output from the baseload to the peaking rate was about 2 minutes.

INTRODUCTION

The Hot Dry Rock (HDR) geothermal reservoir at Fenton Hill, New Mexico was flow tested for a 9-week period from May through July of 1995. This renewed flow testing has been referred to as Reservoir Verification Flow Testing (RVFT) (Brown, 1995). Near the end of this period, following 18 days of steady-state flow testing at a backpressure of 2200 psi, a 6-day series of cyclic flow tests was performed. For a period of 4 hours each day, the production flow rate was dramatically increased by a programmed reduction in the surface backpressure at the production well. Collectively, this series of cyclic flow tests is referred to as the Load-Following Experiment, with the objective of studying the behavior of an HDR reservoir under a simulated demand for enhanced power production for a period of 4 hours each day.

HIGH-PRESSURE FLUID STORAGE NEAR THE PRODUCTION WELL

Based on the results of extensive transient and steady-state flow and pressure testing over the past 10 years, it is apparent that the HDR reservoir at Fenton Hill is comprised of a sparse, multiply interconnected set of pressure-dilated joints in a very large volume of hot crystalline rock. The ratio of fluid to rock volume is of the order of 10^{-4}. Within the body of the HDR reservoir, fluid is stored primarily in dilated joints that are mostly jacked open by fluid pressures that are well above the least principal earth stress. Therefore, the main component of the reservoir fluid storage arises from the elastic compression of the rock blocks between pressurized joints.

The pressure gradient across the body of the reservoir, from the inlet to near the outlet, is reasonably gradual. However, for the 10-meter ± region surrounding the production wellbore, the pressure gradient steepens markedly as the pressure drops to the level of the imposed pressure in the wellbore (imposed by the backpressure regulating valve at the surface). This is due to the fact that the joints are progressively more tightly closed by the earth stresses as the flow converges toward the pressure sink represented by the wellbore. This near-wellbore pressure gradient for the production well can be inferred from the set of transient shut-in pressure recovery profiles shown in Figure 1 (DuTeau and Brown, 1993). When the production well is suddenly shut-in, the pressure measured at the surface (a direct measure of the downhole reservoir outlet pressure) rises from 1400 to 3000 psi in less than 3 minutes, indicating that this high pressure level exists in the joint network very close to the borehole production interval.

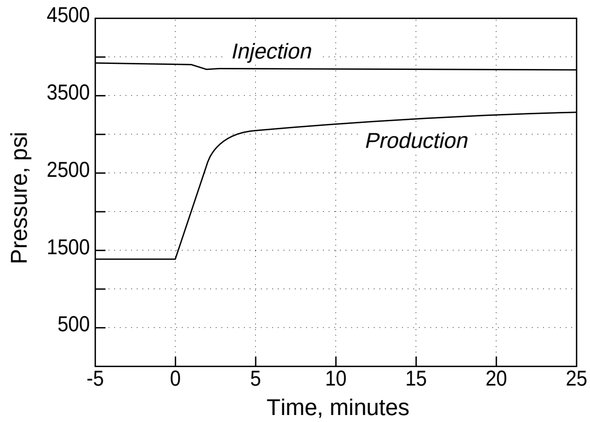

Figure 1. Transient Shut-in Pressure Profiles for the Injection and Production Wells.

Conversely, when the production well backpressure is suddenly *decreased* from an elevated level of 2200 psi, this steep pressure gradient region rapidly extends radially further into the body of the reservoir, effectively draining -- i.e., depressurizing -- a significant zone of fractured rock surrounding the production borehole. After 4 hours of continuous low-backpressure operation, this zone of depressurized joints probably extends radially outward several tens of meters from the borehole.

EXPERIMENTAL RESULTS FROM 1993

In May of 1993, at the end of the Long-Term Flow Test (LTFT) at Fenton Hill (Brown, 1994), a series of 3 cyclic flow tests was performed to gain an understanding of how an HDR reservoir behaves during cyclic production. For this testing, the reservoir was produced for 16 hours at a very low flow and a very high backpressure, and then for 8 hours at a very high flow and a low backpressure (Brown and DuTeau, 1995). Figure 2 shows the injection and production pressure profiles for these three cycles and Figure 3 shows the corresponding flow profiles. During this entire period of cyclic production, the pressure at the injection well was maintained at about 3960 psi by a controlled, but variable, injection rate. The most striking feature of these cyclic production tests was the degree of enhanced production flow that was obtained for a period of 8 hours each day -- an average of about 145 gpm compared to a previous steady-state level of 90 gpm near the end of the LTFT in April 1993, for very similar injection conditions. Funding limitations prevented further experimental investigation of this enhanced flow phenomenon until the summer of 1995.

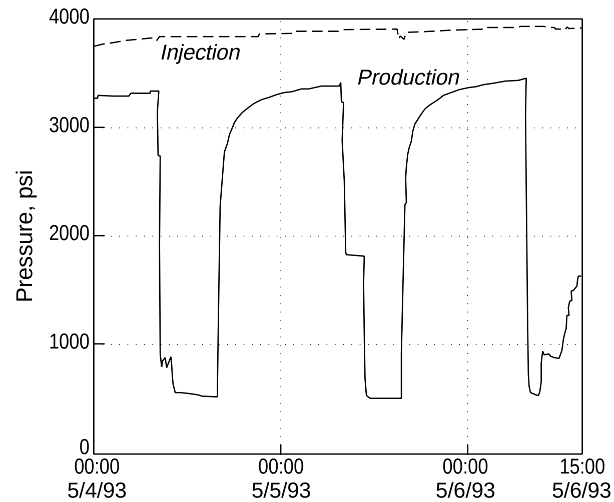

Figure 2. Injection and Production Pressure Profiles During the 3-Day Cyclic Flow Experiment in Early May, 1993.

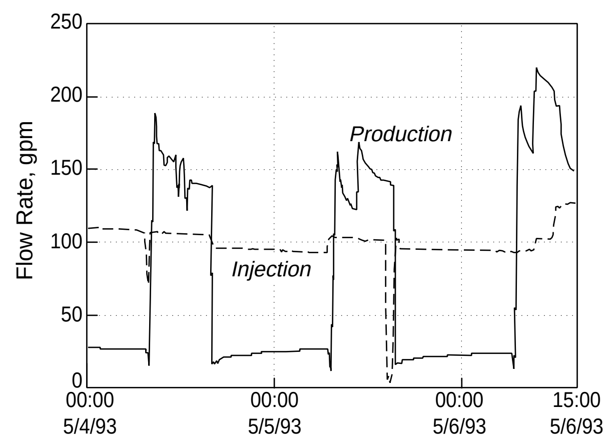

Figure 3. Injection and Production Flow Rate Profiles During the 3-Day Cyclic Flow Experiment.

THE JULY 1995 LOAD-FOLLOWING EXPERIMENT

Starting on July 3, 1995, the Fenton Hill HDR reservoir was again tested in a cyclic production mode, but now in a much more controlled fashion than the testing done in May 1993. This series of cyclic tests was begun from a well-established steady-state high-backpressure operating condition that had been maintained for the previous 18 days (Brown, 1995). The operating data for the precursor steady-state reservoir flow test are given in Table I.

Table I

Reservoir Performance at a Backpressure of 2200 psi as Measured during the RVFT	
Dates Measured:	June 27-29, 1995
Injection Conditions:	
Flow Rate, gpm	124.2
Pressure, psi	3960
Production Conditions:	
Flow Rate, gpm	99.0
Backpressure, psi	2200
Temperature, ˚C	183

Figure 4 shows the profiles of production pressure, and injection and production flow rates for the entire 6 cycles of the Load-Following Experiment. As is obvious from this figure, reservoir operation during the first cycle, which was run in pressure control, was a learning experience. The control system on the injection well worked adequately until the 4-hour pulsed flow period was over, and then human error produced an unscheduled shutdown of both the injection pump and production system. The second cycle, on July 4, was also run in pressure control, but with much better results.

The last 4 cycles were run in flow control after the appropriate rates for the baseload and peaking flows had been determined from the pressure control experiments.

LAST TWO CYCLES OF THE LOAD-FOLLOWING EXPERIMENT

Figure 5 shows expanded-scale profiles for the last two cycles of the Load-Following Experiment. In flow control, the production well backpressure was continually and automatically adjusted by the control system to maintain two essentially constant production flow rates for these two 24-hour periods. The final demand flow rates were:

149.5 gpm for 4 hours
92.2 gpm for 20 hours.

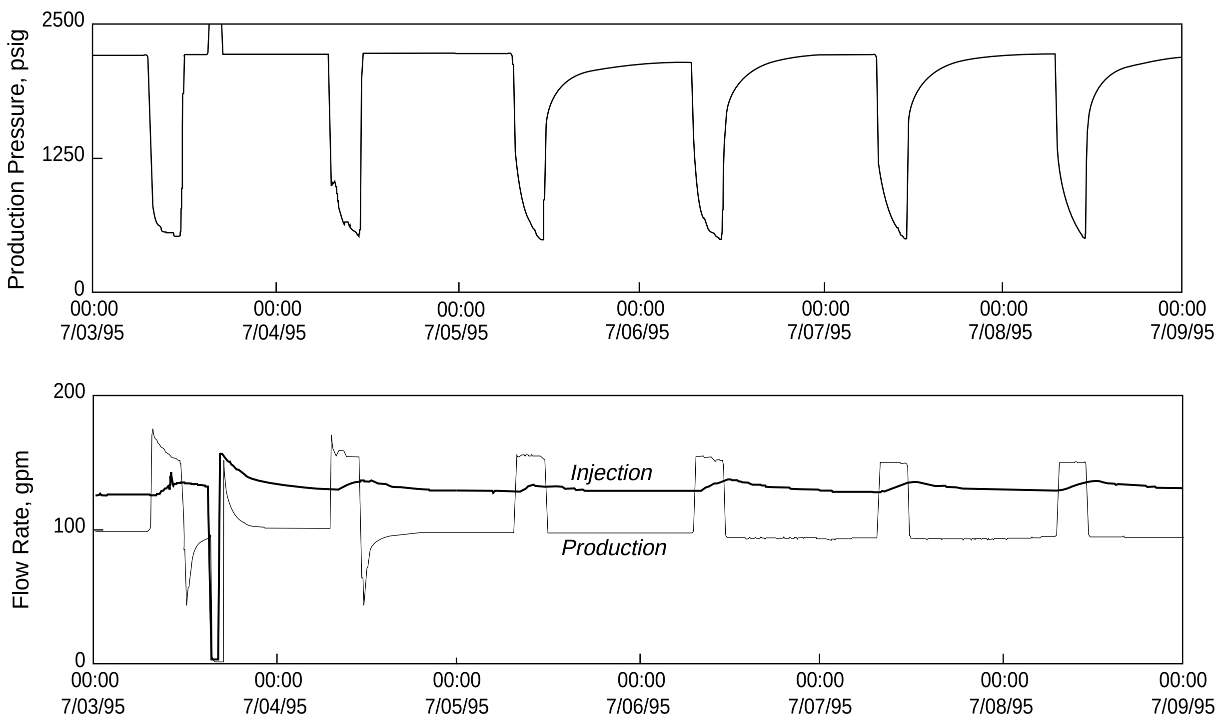

Figure 4. The Six Day Cyclic Load-Following Experiment in July 1995.

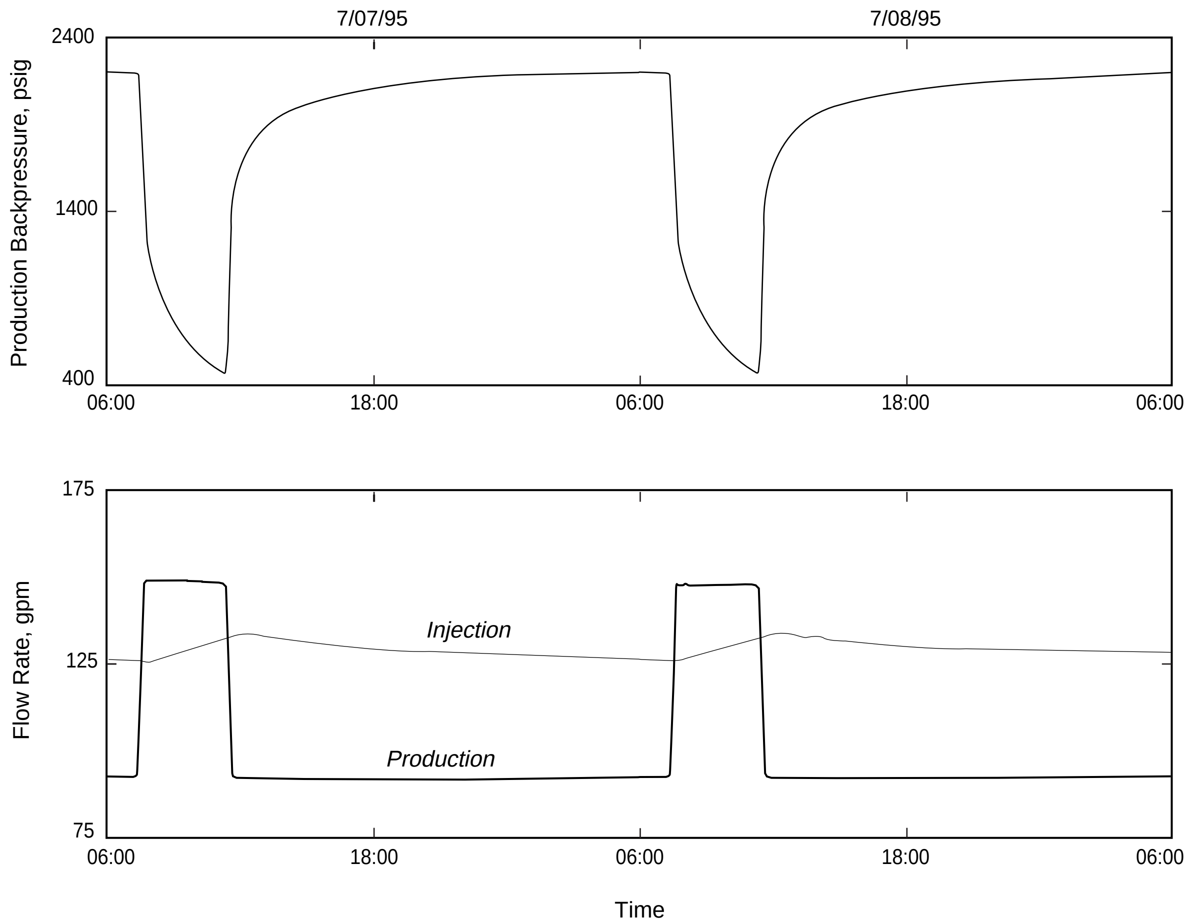

Figure 5. The Last Two Cycles of the Load-Following Experiment.

Table II presents the reservoir performance data for the sixth -- and last -- cycle of the Load-Following Experiment.

Table II

Reservoir Performance Results for the Sixth Cycle of the Load-Following Experiment			
Averages:	4-Hr Peaking	20-Hr Baseload	24-Hr Overall
Injection Flow, gpm	129.3	129.6	129.6
Production Conditions:			
Flow Rate, gpm	146.6	92.4	101.6
Temperature, ˚C	188.7	182.9	183.9
Thermal Power, MW	6.12	3.72	4.11

During the sixth cycle, the increase in power during the 4-hour enhanced production period was 64.5% over the baseload level of 3.72 MW, while the increase in flow rate was 58.6%.

The overall average production flow rate for the last 24-hour cycle was 101.6 gpm, 3.9% greater that the steady-state level of 97.2 gpm existing on the morning of July 3, just prior to beginning the 6-day sequence of load-following experiments. Similarly, the mean production temperature was 183.9°C, up slightly from the 182.7°C level existing on July 3. These average flow and temperature levels show that there was a meaningful overall enhancement in the reservoir performance, when compared to preexisting steady-state levels, by operating in a cyclic mode. This was enough to almost completely compensate for the flow decrease resulting from the increase in back-pressure from 1400 psi to 2200 psi that had been previously noted during the LTFT in 1993, as shown in Figure 6.

The production temperature profile for the sixth cycle of the Load-Following experiment is shown in Figure 7. During the 4 hours of enhanced production, the production temperature increased from 181.6°C to 192.1°C, for a net temperature change of 10.5°C.

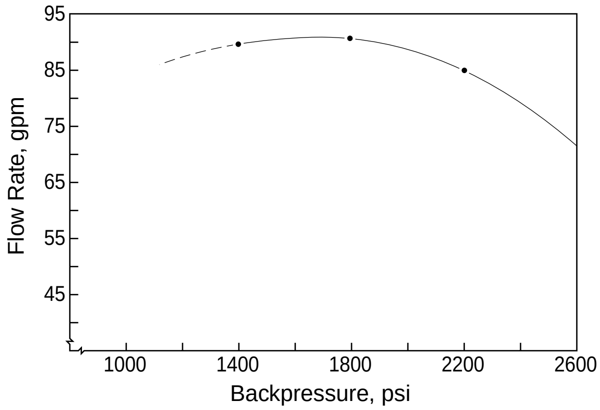

Figure 6. Variation of Production Flow Rate With Backpressure for an Injection Pressure of 3960 psi, as Measured During the LTFT.

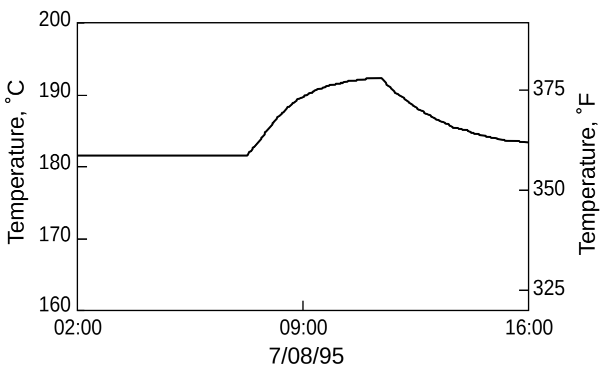

Figure 7. The Production Temperature Profile for the Sixth Cycle of the Load-Following Experiment.

This small change in temperature during the daily peaking power production should have a minimal effect on the integrity of the production casing and surface piping. In operations at Fenton Hill extending over the past 10 years, the production wellbore has been repeatedly cycled from full production temperature down to the geothermal gradient with apparently no adverse effects.

CONCLUSIONS

A unique new method for operating an HDR reservoir to produce both baseload and peaking power has beenbaseload operation that was within only a few percent of the previously determined optimum steady-state operating conditions. The principal objection to cycling the production from an HDR reservoir has been the temperature cycling induced in the production wellbore. However, in this present method of surging the production flow from a baseload operating condition, the temperature excursions were limited to only about 10°C.

The demonstration of this load-following capability could greatly increase interest in HDR geothermal systems by electric utilities because providing for surges in electric power demand is one of their major concerns at present.

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